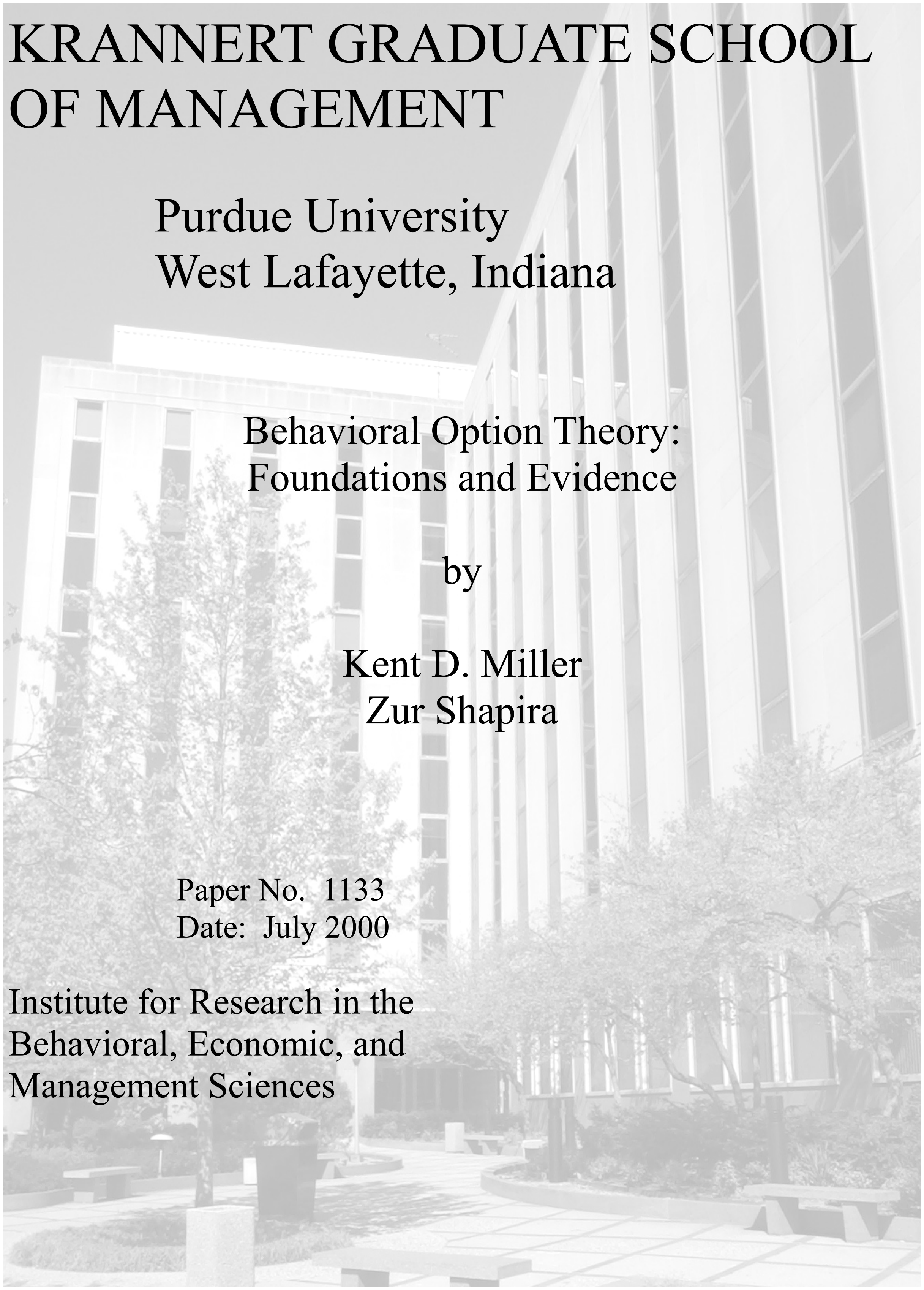

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Behavioral Option Theory: Foundations and Evidence

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BEHAVIORAL OPTION THEORY: FOUNDATIONS AND EVIDENCE

Valuing real options is not an easy task. Their idiosyncratic nature eliminates the market discipline underlying financial option pricing formulas and allows individual risk preferences and biases to enter into option pricing. This study applies behavioral decision theory to option pricing. The resulting hypotheses were tested using option pricing questionnaire data from graduate business students. The evidence indicates risk aversion, discount rates that vary with the option time horizon, and attention to irrelevant outcomes affect subjective option valuations.

The development of option pricing theory (e.g., Black & Scholes, 1973; Merton, 1973) has been hailed as one of the major innovations in financial economics. This development has sparked many innovations in finance and given impetus to the proliferation of derivative instruments since the 1970s. Options allow purchasers to transfer to sellers the risks associated with financial instruments and commodities.

More recently, option theory has been applied outside of finance to what Myers (1977) labeled “real options.” Real options derive their value from the price fluctuations of real—rather than financial—assets. Holders of real call options have the right, but not the obligation, to expand their investments at prices that may be advantageous relative to the prevailing market prices. A real put option confers the right to sell at a potentially advantageous price. Real options become valuable when acquiring tangible or intangible assets requires sunk investments under uncertainty (Dixit & Pindyck, 1994). Real options grant management the prerogative to defer, expand, contract, abandon, or switch projects (Trigeorgis, 1996: ch. 1). Real option pricing involves assigning values to investments in flexibility.

There is a growing awareness that many of the decisions managers face can be characterized as real option investment problems. Investments in flexibility to grow a business (e.g., development or licensing of core technologies) can be thought of as call options. Fostering multiple distribution channels and the capacity to serve distinct geographic markets can be seen as investments in future growth and switching opportunities. Flexibility to downsize or exit a business is a real put option. For example, investments in developing a flexible workforce and production capacity can provide an option to discontinue products.

Despite recent advances, the relevance of option theory to valuing real options is not straightforward. Standard approaches to option pricing rely upon arbitrage arguments. The key insight provided by Black and Scholes (1973) was that shares of a stock and options on the same stock—both being risky—can be combined to form a riskless portfolio. The return to such a portfolio must be the risk-free rate. Any deviation from the risk-free rate presents a riskless profit opportunity that should disappear quickly due to trading by arbitrageurs. This arbitrage argument eliminates consideration of individual risk preferences and results in a single prevailing market price for each option (Cox, Ross, & Rubinstein, 1979; Trigeorgis & Mason, 1987).

One crucial assumption in financial option pricing is that options have underlying assets that are traded. For options on financial assets such as stocks, this assumption holds. If the underlying asset is not directly traded but has returns matching those of an available traded asset (such as a stock or commodity), this "twin security" can be used to determine the option value using the arbitrage approach (Trigeorgis & Mason, 1987). However, for real options the assumption of an available traded "twin security" is unlikely to hold because the underlying assets are often idiosyncratic and not traded. As a result, option pricing approaches based upon arbitrage arguments generally do not apply to real options.

Valuing options on idiosyncratic nontraded assets is a challenge managers face frequently when making capital budgeting decisions under uncertainty. In such settings, how do option buyers and sellers value options? How do risk preferences affect option valuation? Are there systematic biases in managers' perceptions of option value? What role do subjective discount rates play in real option valuation? These are important behavioral questions. At present, we have little systematic theory development and empirical evidence addressing these important issues.

Bowman and Hurry (1993) were among the first to call for studies bringing behavioral perspectives to real option research. Kogut and Kulatilaka (1994) suggested that managers can be myopic when valuing real options. Lander and Pinches (1998) indicated that managers have limited understanding of existing option pricing models and the real option pricing problems they face often involve violations of the assumptions of these models. McGrath (1999) pointed out the potential role of cognitive biases in real option investments. Very little research has followed up on these suggestions by investigating the decision heuristics and biases associated with evaluating real options.

The limited evidence we do have about managers' assessments of real options indicates deviations from the normative models. Howell and Jägle (1997) sought to determine whether managers' intuitive valuations of real growth options agree with the normative Black-Scholes (1973) model. They asked managers to make hypothetical decisions on a series of growth option investments written up as case studies. Their cases varied the expected values of cash flows, volatility, and option duration. They found managers' valuations evidenced significant deviations from Black-Scholes valuations and showed both under- and over-valuations, depending on the problem specified.

Shefrin and Statman (1993) argued that financial derivatives may be subject to behavioral effects causing perceived valuations to deviate from normative finance models. They focused on four behavioral considerations for the design of financial products: prospect theory, hedonic framing, behavioral life cycle theory, and cognitive errors. They argued that because of these behavioral considerations, investors may prefer one financial product to another even when both have identical cash flows. Consistent with this view, Steil (1993) invoked findings from behavioral decision theory to explain deviations from optimal hedging decisions.

Busby and Pitts (1997) collected survey data from finance directors at 44 large U.K. firms. In agreement with the Black-Scholes option valuation parameters, most respondents indicated that option value falls with the exercise price, while maturity period and returns uncertainty are positively related to option value. Respondents were ambivalent about the effect of interest rates on option value. Although finance directors recognized real options in a wide range of projects, their organizations had not implemented systematic approaches to real option valuation, but relied on ad hoc evaluation methods.

Past research on decision making under uncertainty raises further reasons to suspect that subjective option values may deviate from prices derived using normative models. For example, people exhibit systematic deviations from the predictions of expected utility theory (see, e.g., Kahneman, Slovic, & Tversky, 1982; Schoemaker, 1982). Fox, Rogers, and Tversky (1996) showed that financial option traders' judged probabilities (based on valuations of uncertain prospects) violate expected utility theory in ways similar to those of other populations. The existence of such biases in the context of simple probabilistic decisions ought to alert us to the potential for biases in the more complex contexts of real option identification, valuation, and exercise decisions. Not only are these decisions probabilistic, they involve inter-temporal considerations not incorporated in the simple single-period decisions that have been studied extensively in behavioral decision theory. Existing treatments of real options also do not incorporate insights from research on managerial responses to risk and risk-taking.

This study contributes theoretical propositions and empirical evidence regarding managers' perceptions of option values. In contrast with the finance literature—which focuses on option pricing in efficient markets—we consider the subjective aspects that arise when option markets are inefficient. Because real option markets are generally inefficient or nonexistent,[1] allocating resources to purchase real options is an inherently subjective process. This study offers initial evidence on how managers actually formulate option values. This is the first study to examine subjective valuations of calls and puts from both buyer and seller perspectives. It also contributes evidence on the effects of specific option characteristics, such as exercise price and option duration, on perceived option values.

The next section starts with a presentation of the basics of option theory and then draws on behavioral decision theory to explain subjective option pricing by managers. The theoretical arguments motivate hypotheses to be tested empirically. The latter portion of this paper examines data obtained from graduate business school students to test whether option values reveal the biases predicted by behavioral decision research.

FOUNDATIONS OF BEHAVIORAL OPTION THEORY

We use the term "behavioral option theory" to refer to the application of behavioral decision theory to predict managers' responses to option valuation problems. We propose that the basic elements of behavioral option theory have to do with the characteristics of real options on the one hand, and with the behavior of investors under conditions of risk on the other. We begin by defining the two kinds of options (calls and puts) and key parameters affecting option values. We then develop theoretical background and hypotheses on behavior when buying and selling options.

Option Theory Basics

There are two types of options: calls and puts. A call option provides its holder the possibility (but not the obligation) to purchase a particular asset at a given price (known as the exercise or strike price). A put option confers the right to sell an asset at a specified exercise price. The option price is the value of the option as determined at the time of exchange between buyer and seller. Call option holders will exercise the option only if the price of the underlying asset exceeds the exercise price. Put options will only be exercised if the asset price falls below the exercise price. In such cases, we say that the option is "in the money".

Options with a fixed exercise date on which the option can be exercised are known as European options. This designation distinguishes them from American options, which can be exercised at anytime during their duration (the time up to their expiration).

The willingness of buyers and sellers to participate in option trading is based on differences in expectations about the future value of an asset and/or differences in risk preferences. An attractive feature of options is that the option purchaser engages in a small transaction relative to buying or selling the underlying asset itself. The buyer makes a small "down payment" conferring the right to engage in a larger transaction in the future. A call option remains unexercised if the price of the asset drops below the exercise price. A put option remains unexercised if the asset price stays above the exercise price. In both cases, the purchase of an option can be viewed as the willingness to incur a current cost (i.e., the option purchase price) in order to avoid future downside outcomes. Hence, the use of options to manage risk is consistent with managers' risk assessments in terms of downside outcomes (March & Shapira, 1987; Miller & Leiblein, 1996; Miller & Reuer, 1996).

The simplest type of option pricing problem can be motivated from the risky choice problems commonly found in behavioral decision theory. We often use a simple two-branch decision tree to portray such a decision, as in Figure 1(a). The simple specification of a risky choice offers payoff x_1 with probability p_1 ($0 < p_1 < 1$) and payoff x_2 with probability p_2 ($p_1 + p_2 = 1$). This simple lottery has an expected value of $p_1x_1+p_2x_2$ and its associated expected utility can be represented as $U(x_1, p_1; x_2, p_2) = p_1u(x_1) + p_2u(x_2)$.

Insert Figure 1 about here

This standard lottery problem assumes commitment to play a lottery must be made <u>before</u> the outcome is known. No allowance is made for the possibility that the decision-maker may choose to wait and view the outcome before deciding whether to obtain the lottery outcome. Allowing for waiting prior to committing to an uncertain outcome is the key difference between simple option decisions and the standard risky lottery portrayed in microeconomics and behavioral decision theory. If x_1 is a gain and x_2 is a loss, holding the call option truncates the distribution of outcomes relative to holding the lottery. Figure 1(b) depicts the possible outcomes associated with holding a call option on the lottery in Figure 1(a).

The similarities between simple option pricing and lottery problems suggest that behavioral decision theory may help us understand subjective option valuations. In particular, two major aspects studied in behavioral decision theory are relevant for examining perceived option values: risk attitudes and time preferences.[2] The former is important because options are inherently insurance instruments (i.e., for the purchasers, they mitigate the losses that can result from risky investments). Time preferences arise because the cash flows resulting from buying and selling options are realized in the future.

In the discussion that follows, we examine some of the relevant findings in behavioral decision theory regarding these two aspects of option valuation and derive a set of testable hypotheses. Our discussion focuses on the questions: (1) What would someone be willing to pay for an option on a lottery outcome? (2) For what price would someone be willing to make available such an option? In seeking to answer these questions, we need to consider the perspectives of both buyers and sellers in call and put option transactions.

Risk Preferences and Option Pricing

Classical analyses of risky choice (cf. Arrow 1965; Pratt, 1964) assumed that individual decision makers' attitudes toward risk could be described in terms of the parameters of their utility functions. Most writings on risk attitudes assumed risk aversion. When faced with a choice between a sure outcome and a risky alternative with the same expected value, a risk averse individual will choose the sure outcome. It follows that decision makers must be compensated for variability in possible outcomes. For example, Levy and Sarnat (1984) studied 25 years of investments in mutual funds and observed that investors were averse to the variance of returns.

Evidence suggests that the same person may behave as risk averse and risk seeking in different contexts (Shapira, 1995; Slovic, 1964). Kahneman and Tversky (1979) observed that when dealing with risky alternatives with gains as the possible outcomes, people appear to be risk averse; but if they are dealing with a risky alternatives with possible loss outcomes, people tend to be risk seeking. These are the two essential propositions of prospect theory.

We follow the logic of prospect theory to develop hypotheses regarding the effects of risk preferences for purchasers and sellers of call and put options.[3] Hence, there are four distinct cases to consider: (1) purchasing a call, (2) selling a call, (3) purchasing a put, and (4) selling a put. In developing the hypotheses and questionnaire, we assumed the call option buyer and put seller have no pre-existing risk exposures.[4] The call option buyer seeks exposure to a potential upside outcome. The put seller is willing to be exposed to a potential loss. By contrast, we assumed the call seller and put buyer have pre-existing exposures they seek to hedge.[5] The call seller wants to lock in the upside potential rather than remain exposed to an uncertain outcome. The buyer of the put hedges a potential loss.

Several assumptions are carried throughout our discussion. We assume a common underlying asset that pays a positive sum, x_1, with probability p_1, and a negative sum, x_2, with probability p_2. The option purchase price is designated y. The option purchase decision must be made in an initial period and the payoff is determined in a subsequent period. We assume that the utility associated with the initial option transaction and the subsequent option payoff are separable and additive. That is, buyers and sellers engage in a form of mental accounting, as presented by Thaler (1985), that distinguishes the initial option transaction from the subsequent option payoff transaction. For simplicity, we assume the exercise price is zero. The arguments made here are based on the prospect theory findings of risk aversion in the domain of gains and risk aversion in the domain of losses.[6] Readers interested in proofs of each of the hypotheses should see the endnotes.

Purchasing a call. Consider first the purchase of a call option for a buyer. The call option confers the right to wait until the lottery outcome is known before deciding whether to accept or decline its outcome. After forfeiting the option purchase price, the payoff function becomes $\max(x_1,0)$, and the expected payoff is p_1x_1. Hence, the possible outcomes are as given in Figure 1(b).

Call options will only be exercised if they are in the money, so the possible outcomes for their holders are either gains or zero. Because these probabilistic outcomes are in the domain of gains, prospect theory suggests call option purchasers should exhibit risk aversion. Risk aversion is expressed by offering to pay a price that falls short of the expected payoff of the option (p_1x_1). Hence, if call option purchasers are risk averse, we would expect:

Hypothesis 1: Purchasers price call options at discounts relative to their expected payoffs.[7]

Selling a call. The call option seller's situation is different from that of the call option purchaser. The call option seller is already exposed to the probabilistic outcome associated with holding the lottery (as shown in Figure 1(a)) and seeks to exchange a possible gain for a sure current call option sale price. The possible gain is x_1 with probability p_1. A risk neutral option seller will accept a price of no less than p_1x_1. A risk averse option seller would be willing to discount this price. After receiving the option price (y), the call option seller faces the residual probabilistic outcomes shown in Figure 1(c). In other words, the seller is still exposed to the possible loss x_2 with probability p_2.

In summary, the seller is initially exposed to the lottery (Figure 1(a)), sells the potential gain portion of the lottery as a call option (Figure 1(b)), and retains the potential downside outcome (Figure 1(c)). For lottery holders, call option sales involve exchanging a probabilistic gain for a sure gain in the form of an option price. Because the decision is framed in terms of the domain of gains, prospect theory indicates the call option seller should exhibit risk aversion. Thus, the seller should be willing to accept a discount relative to the option's expected value.

Hypothesis 2: Sellers price call options at discounts relative to their expected payoffs.[8]

Purchasing a put. We now turn our attention to put options. Consider an individual who is exposed to a potential loss, who seeks to hedge the downside component of this exposure by purchasing a put option. The value of the put option comes from the possibility of avoiding the loss x_2, which occurs with probability p_2. A risk-neutral individual would be willing to pay up to the absolute value of the expected loss for the put option, i.e., $|p_2x_2|$. By contrast, a risk seeker, who would actually prefer to hold the risky asset, would offer to pay a price discounted relative to the absolute value of the expected loss.

By purchasing a put option, the individual shifts exposure from the lottery (Figure 1(a)) to just the gain portion of the possible outcomes (Figure 1(b)), and eliminates exposure to loss portion of the distribution (Figure 1(c)).[9] Hence, the put option purchase affects only potential losses, not gains. Prospect theory indicates buyers' valuations should reflect risk seeking in the domain of losses. Buying a put option does not affect potential gain outcomes; it simply shifts from a probabilistic loss to a fixed loss (given by the put option purchase price) and retains the upside gain potential. The convexity of the prospect theory value function for loss outcomes suggests the following hypothesis:

Hypothesis 3: Purchasers price put options at discounts relative to their expected payoffs.[10]

Selling a put. The fourth situation to consider is that of the put option seller. Put option sellers have no pre-existing exposures. Rather, they make discretionary choices to take on avoidable potential losses. After receiving the option price, the put option seller's possible payoffs are depicted in Figure 1(c).

Put sellers' preferences should reflect risk seeking in the domain of losses. Because of convex preferences regarding losses, a risk seeking put option seller should be willing to accept a price discounted relative to the expected loss. Essentially, they require compensation less than their expected loss to take on the risky put option. As such,

Hypothesis 4: Sellers price put options at a discount relative to their expected losses.[11]

Time Preferences and Option Pricing

Real option theory highlights the potential benefit from waiting (Ingersoll & Ross, 1992; McDonald & Siegel, 1986; Venezia & Brenner, 1979). While waiting, managers can incorporate new information into their decisions. Granted, waiting may have its costs as well, as opportunities pass. The temporal dimension of options introduces discounting into option valuation.

Studies of managerial risk taking (MacCrimmon & Wehrung, 1986; Shapira, 1995) show that managers consider risk taking in a longitudinal frame and often delay decisions on risky prospects. In addition, they believe that they can exercise post-decisional control (Langer, 1975; Shapira, 1995). Thus, managers' evaluations of real options should also depend on the interplay of these two forces: time preferences and belief in post-decisional control. Although managers have been criticized for their "illusion of control," their predisposition to make incremental adjustments is at the heart of real option thinking.

Both economic considerations of opportunity cost and the psychology of waiting lead to discounting future outcomes. Economic psychologists following Strotz's (1956) dictum, have examined the preferences of individuals for immediate versus delayed rewards. Similar to the delayed gratification literature in developmental psychology (Mischel, Shoda, & Rodriguez, 1989), the findings suggest that people have a strong preference for current over delayed payoffs, and future rewards are discounted at very high rates (Loewenstein & Prelec, 1992).

In order to keep our option pricing problems as simple as possible, we examine the discounting of options with zero exercise prices. This avoids confounding exercise price and discounting effects. If option transactions occur prior to the payoff, we can apply the risk-free discount rate to determine the present value of receiving the certainty equivalent payoff. However, the actual discount rate used by managers may deviate from the normative risk-free rate (Benartzi & Thaler, 1995; Loewenstein, 1987). Smith and Nau (1995) reported that managers tend to use the risk-adjusted rather than the risk-free discount rate when valuing options.

Behavioral research on discounting has not considered option valuation. Nevertheless, the findings from this research, point to possible discounting biases associated with the temporal dimension of real options. Benzion, Rapoport, and Yagil (1989) examined responses to questionnaire items involving 6-month, 1-year, and 4-year delays. Their data indicated lower discount rates the longer the time horizon, and the rate of decrease in the discount rate decreases with the time horizon. These findings corroborated earlier findings by Thaler (1981). We reexamine these previous research findings in the context of option pricing. Based on previous research on discounting, we expect:

Hypothesis 5: Discount rates decrease with option duration, and the steepness of decline decreases with time.

Exercise Prices and Option Pricing

Up to this point, our analysis of option valuation assumed no cost associated with exercising the option, i.e., a zero exercise price. We now turn our attention to the implications of introducing a positive exercise price. For a call option with an exercise price of e, where $x_1 > e > 0$, the payoff to the option buyer is $\max(x_1\text{-}e, 0)$. The payoff associated with the best possible outcome shifts down by e relative to the call option with a zero exercise price. The lower bound is zero because the option will not be exercised if it is out of the money.

We have already characterized both buyers' and sellers' call option decisions as reflecting risk aversion. Each of these decisions reflects concave preferences in the domain of gains. This leads to discounting options relative to their expected values. Following similar reasoning, we anticipate that the acceptable price will decline by less than the shift in expected value (p_1e) when moving from an option with a zero exercise price to a positive exercise price.

Hypothesis 6: Call option sellers and buyers discount exercise prices.[12]

Now consider the implications of exercise prices for put option values. We already characterized put option buyers and sellers as framing their decisions in the domain of losses. The put option buyer—seeking to insure against a loss—pays the purchase price y and reduces the potential loss to $-e$ rather than x_2 (where $-e>x_2$). Because of risk seeking, retaining this potential loss will not reduce the offer price by as much as the expected loss. Moving from a zero exercise price to a positive exercise price causes a drop in option value that is less than the expected value of the exercise price (p_2e).

After receiving the option price, the put option seller faces a payoff of zero (if x_1 occurs) with probability p_1 or a loss of x_2+e with probability p_2. This reduction in potential loss (relative to have an exercise price of zero) is under-appreciated by the risk seeking option seller (relative to the risk-neutral valuation). The increase in put option value when going from a zero exercise price to a positive exercise price is less than p_2e. Thus, under risk seeking, we expect:

Hypothesis 7: Put option sellers and buyers discount exercise prices.[13]

METHODS

Sample

In order to gather some initial data to explore our hypotheses, we elicited voluntary responses from 67 part-time students enrolled in a MBA program at New York University. Two questionnaires were unusable because of missing data. One questionnaire was deleted because the respondent provided eight negative valuations. Option prices should always be nonnegative so this was taken as an indication that this particular respondent misunderstood the questionnaire items. There were two other instances of isolated negative values in the data set. These were deleted while the remaining data for these two respondents were retained. Hence, the resulting sample size was 64.

The respondents' ages ranged from 23 to 37 years with a median age of 29. Sixty-three percent were males and 37% were females. Fifty-seven percent of the respondents indicated they learned about option pricing in a class that covered other finance topics. Eleven percent had taken a class focused on options. Eight percent of the respondents indicated they had work experience related to options trading, while 11 percent indicated they have traded options for their own accounts. Just over one-third of the respondents (35 percent) indicated no prior background in option theory. About 40 percent were employed by a financial institution at the time of the study.

Questionnaire

The questionnaire consisted of thirty-six option valuation problems. The options described in these problems were expressed in the simplest terms possible. Each involved only two possible outcomes for the values of the underlying assets and, to simplify computation, probabilities were set at fifty percent throughout the questionnaire.[14] Pretesting among 10 graduate students resulted in refinements of the wording of the option pricing problems as well as the instructions. The instructions included brief explanations of call and put options, and related terms such as "exercise date" and "exercise price." Every effort was made to make the questionnaire understandable even to those with little or no previous background on options. Table 1 indicates the kinds of items included in the questionnaire. For each item, respondents were asked to indicate the maximum price they would be willing to pay to buy the option or the minimum they would be willing to receive to sell the option.

Insert Table 1 about here

Part I of the questionnaire consisted of twelve option pricing problems—three problems each for call buying, call selling, put buying, and put selling. These problems used the values $(x_1, x_2) = (1000, 500), (1000, 0), (1000, -1000)$.[15] The x_2 value of -1000 is an irrelevant loss outcome for call option valuation and an irrelevant gain outcome for a put option. These outcomes are irrelevant because options remain unexercised if they are not in the money. The magnitude of x_2 below zero should not affect option values. Hence, the values assigned to options using x_1 and x_2 values (1000, –1000) should not differ from those using values (1000, 0). Deviations in values between these two problems would indicate biases associated with the size of irrelevant outcomes.

The items in Part II were comparable to those in Part I using $(x_1, x_2) = (1000, 0)$. The only difference was that they involved waiting until a specific future time to resolve the value of the investment before the option could be exercised. As such, all of our discounting problems involved European options. The twelve items in Part II considered six-month, one-year, and four-year time horizons.

The twelve items in Part III differed from those in Part I only in that they involved positive exercise prices.[16]

Analysis

Hypotheses 1 through 4 indicated we expect the mean option prices fall below the risk-neutral valuation. The directions of these hypotheses indicate one-tailed tests are appropriate. If we let μ_0 and μ designate the risk-neutral valuation and the population mean, respectively, these hypotheses indicate $\mu \leq \mu_0$. For the set of reported option values V_i (i=1,...n), let $S_n^2 = \sum_{i=1}^{n} \left(V_i - \overline{V}_n\right)^2$. The test statistic $t = \dfrac{n^{1/2}\left(\overline{V}_n - \mu_0\right)}{\left[S_n^2/(n-1)\right]^{1/2}}$ has a t distribution with n-1 degrees of freedom (DeGroot, 1975: 414).

As noted above, the magnitude of the loss outcome is irrelevant when valuing a call option and the magnitude of the gain outcome is irrelevant when valuing a put option. To test for independence from the magnitude of irrelevant outcomes, we considered whether the within-respondent differences of two consecutive items in the questionnaire, one of which introduces an irrelevant outcome, were significantly different from zero using a one-tailed t test.

The data from Part II of the questionnaire, in combination with four items from Part I, allowed us to compute the implicit discount rates for the periods ending at 6, 12, and 48 months. Let V_t represent the reported value of an option with an outcome realized in period t. For the first two six-month periods, the discount rate was computed as $r_t = (V_t / V_{t+1}) - 1$. Computation of the discount rate for the period from month 12 (t=2) to 48 (t=8) assumed compounding every six months, i.e., $r_{t=8} = (V_2 / V_8)^{1/6} - 1$.

In Part III of the questionnaire, we were primarily interested in whether introducing an exercise price resulted in deviations from risk neutral option values relative to the respondent's values for comparable options without exercise prices in Part I. If we designate the probability of exercising the option as p_2, introducing a positive exercise price (e) should shift the option value by p_2e under risk neutrality. If expressed valuations are consistent with risk neutrality, we ought to observe that the within-respondent differences in option values without and with the exercise price (V_1-V_2) should equal p_2e. Using a one-tailed t test allows us to formally test for systematic deviation from risk neutral valuation when introducing an exercise price.

RESULTS

Our tests of hypotheses 1 through 4 used data from simple option pricing problems that do not raise considerations regarding exercise price or temporal discounting. These simple questionnaire items provide a baseline set of option value data against which to compare subsequent values involving more complex option pricing considerations. Of primary concern in testing hypotheses 1 through 4 was whether respondents tend to price options at discounts relative to their expected values. Call option buyers and sellers were expected to price options at a discount relative to their expected value, reflecting risk aversion (H1 and H2). Put option purchasers and sellers were hypothesized to be risk seeking (H3 and H4) as evidenced by discounting puts relative to their expected values.

Table 2 reports descriptive statistics for the twelve simple option pricing items in Part I of the questionnaire. Prices for buying calls (items 1 through 3), selling calls (items 4 through 6), and buying puts (items 7 through 9) reflect consistent—and in some instances, quite substantial—discounting relative to expected values. Two of the three prices for selling put options (items 10 through 12) reveal discounting. The mean response to item 11 is an anomaly in light of the responses to items 10 and 12. The mean for item 11 was not significantly different from its expected value. The t statistics are for one-tailed tests of equality of the subjective valuations with their expected values. The t statistics are negative and highly significant ($p<.01$) for all items except 11. In general, the results indicate discounting of both calls and puts relative to their expected values, irrespective of whether the buyer or seller position is assumed. These findings support hypotheses one through four.

Insert Table 2 about here

Data from this initial set of twelve items also provided a basis for testing whether the magnitude of irrelevant outcomes (i.e., losses for calls and gains for puts) affect perceived option values. There were four pairs of items that involved changing only the magnitude of irrelevant outcomes. For example, one call option purchase problem involved an underlying asset with 50 percent probability of gaining $1000 and a 50 percent probability of gaining nothing. The only change in the subsequent problem was to substitute a loss of $1000 as the downside outcome. Such a loss is irrelevant for a call option because it will only be exercised if it is in the money, so the payoff is max(1000, 0) in either case.

For each of the four pairs of items that reflected changes in the magnitude of irrelevant outcomes (2 and 3, 5 and 6, 8 and 9, and 11 and 12), significant differences were found. The t statistic for buying a call was 9.8109, for selling a call, 9.2458, for buying a put, 6.4290, and for selling a put, 7.3721. In all instances, these one-tailed t tests are significantly different from zero (d.f. = 62, $p < .01$), indicating the irrelevant alternatives decrease perceived option values. Hence, changing the magnitude of irrelevant outcomes significantly reduced respondents' option valuations. This occurred despite the items in each of the comparison pairs having the same expected values.

Based on previous behavioral research, we expected discount rates would decrease with option duration, and the steepness of decline would decreases with time (H5). For purposes of computing discount rates, we used only option pricing problems that had relevant outcomes (gains for calls and losses for puts) and zero outcomes. This avoids any confusion due to the magnitude of irrelevant outcomes. Discount rate computations involving division by zero were treated as missing data. The data allowed for computation of four values of the discount rates for each of three time periods. We used the within-respondent mean values for each period as the basis for comparing across individuals.

The initial striking feature of computed implicit discount rates is the large number of negative values. This implies a very counter-intuitive approach of valuing future payoffs more highly than current payoffs. For the first 6-month period, the computed discount rate was negative for 29 of the 63 observations. For the second 6-month period, and the 36-month period from year 1 to year 4, the frequency of negative responses was much lower (7 and 4, respectively). Nevertheless, mean values for the discount rate are positive for each of the three periods, as shown in Table 3. The overall pattern exhibits the expected decline in discount rates as we move from proximate to more distant time periods. The declining rate of decline is also consistent with hypothesis 5.[17]

Insert Table 3 about here

Although the descriptive statistics appear consistent with findings from previous research (e.g., Loewenstein, 1987), we must add a word of caution. Analysis of variance indicated the differences in discount rates across periods were not significant (F statistic = 1.56, $p < .21$). The overall R^2 for the ANOVA model was just 0.016, indicating periods provide little explanatory power.

What emerges from our analysis of discounting is evidence that there is a great deal of intra- and interpersonal inconsistency regarding the effect of variations in duration on option values. These within- and across-respondent disparities decrease the longer the time horizon. Both the frequency of negative implicit discount rates and the standard deviations across respondents decline with greater temporal distance. These are more noteworthy finding than the somewhat weak support for H5, given the insignificant results from our ANOVA model.

The items in Part III of the questionnaire served to determine whether introducing a positive exercise price shifted perceived option value by an amount comparable to the actual change in expected value (i.e., risk neutral valuation). Table 4 reports descriptive statistics for the items in Part III along with the expected values for each of the options. Using 60 as the degrees of freedom (≈n-1) and two-tail tests, the t statistics are significant at the .01 level if their absolute values are at least 2.66. For a one-tail test, the cutoff value is 2.39. The pattern evident in this table is a tendency to overvalue the options with the higher $750 exercise price (items 1, 4, 7, and 10) and undervalue the other options with the lower $500 exercise price.

Insert Table 4 about here

Whereas the t statistics in Table 4 test for deviations from the expected values of each of the options, our primary interest was in the magnitude of the change in perceived value relative to the same options with zero exercise prices. Table 5 reports descriptive statistics for the Part I and Part III questionnaire items that differ only in the exercise price. The "Comparison" portion of the table reports, the mean difference in values for options without and with exercise prices. The column PE is the probability of exercising the option times the exercise price, i.e., the expected change in option value. The reported t statistic is for the test of equality of the shift in valuation equal to PE. For 60 degrees of freedom, one-tailed t values of at least 2.39 are significant at the .01 level. Using this criterion, seven of the twelve differences are significant. All of the significant differences indicate underestimation of the shift in option value due to the exercise price.

Insert Table 5 about here

The results are generally supportive of hypotheses 6 and 7. Call option buyers and sellers evidence shifts in option values that are less than the shifts in expected values (see items 1 through 6 in Table 5). This is consistent with risk aversion. Put option buyers and sellers exhibit significant discounting of the exercise price in four of the six cases (see items 7 through 12), indicating risk seeking in the domain of losses. However, the evidence for discounting the exercise price is least compelling for sellers of put options, where only one of the three items shows significant discounting.

DISCUSSION

There are similarities and differences between financial options and real options. The main difference lies in the fact that financial options are usually written on very specific and traded assets. This allows financial options to be priced with considerable accuracy using the Black-Scholes (1973) or other option pricing formulas. Although such formulas can be applied only under certain conditions (e.g., a European option and strong assumptions about the stationarity of variance), the existence of underlying traded assets makes calculating the value of financial options a relative easy endeavor. By contrast, the absence of traded underlying assets makes valuing idiosyncratic real options difficult. Standard option pricing models do not apply. Managerial discretion enters into valuation decisions. This opens up the possibility for systematic deviations from normative approaches to option pricing. This possibility motivated us to draw from the findings of behavioral decision theory in order to understand managers' thinking about valuing options.

While a major part of the classical discussion of risk tendencies was based on insurance decisions (Arrow, 1965) economists were puzzled by the fact that people buy insurance on the one hand, and lottery tickets on the other. Providing a theory to explain how people can be both risk averse and risk seeking was attempted by Friedman and Savage (1948) who proposed a particular utility function for that matter. Later Markowitz (1952) proposed the introduction of a reference point into utility theory, but it was not until Kahneman and Tversky (1979) came up with prospect theory that the idea of treating risk tendencies as a function of gains and losses relative to a reference point was accepted.

Our analysis of risk taking in the context of valuing options followed the Kahneman and Tversky (1979) tradition. In a sense one can argue that dealing with real options mimics to some degree the insurance/gambling problem. Call option sellers and put option buyers are basically insurance purchasers. Call option buyers and put option sellers may be likened to lottery ticket buyers. We assumed that option buyers and sellers risk tendencies reflect their framing of the option buying or selling decision as involving either a pure gain or a pure loss situation, hence the framing notion of prospect theory applies. Furthermore, Hypotheses 1 and 2 could have been derived form classical utility theory, but the focus on risk seeking in Hypotheses 3 and 4 comes uniquely from prospect theory.

The results supported the contention that call option transactions are framed in the domain of gains and reflect risk aversion (see Table 2). Discounting of put options is consistent with the contention that these transactions are framed in the domain of losses and reflect risk seeking. The results from introducing exercise prices also are consistent with prospect theory expectations (see Table 5).

The ability to incorporate assumptions regarding duration is another key aspect of valuing real options. When volatility per period is constant and the exercise price is fixed, option values increase with duration (e.g., Black & Scholes, 1973). By contrast, our option pricing problems involved decreasing the volatility per period as the time horizon was extended. This created a simple discounting problem, i.e., option values should decrease with the length of time to payoffs. Our subjects generally recognized the need to discount future option payoffs. In general, the subjects' implied discount rates were consistent with other studies demonstrating myopic behavior when valuing future outcomes (cf. Benzion, Rapoport, & Yagil, 1989; Benartzi & Thaler, 1995; Lowenstein & Prelec, 1992). However, their implicit discount rates indicated much more confusion regarding discounting over short time horizons than long horizons. Negative implicit discount rates and wide variance across individuals evidenced confusion regarding short-term (e.g., six-month) discounting.

There are several possibilities for extending this research. In order to limit the length of our questionnaire, this study did not explore the implications of varying the probabilities of alternative outcomes. All probabilities were fixed at 50-50 odds. Future research could vary these probabilities and determine the implications for perceived option value. Of particular interest would be the differences in willingness to pay for options with certain outcomes versus nearly certainty outcomes, and impossible outcomes versus nearly impossible outcomes (Tversky & Fox, 1995). Kahneman and Tversky (1979) identified a strong preference for sure gains relative to highly probable gains. Their "certainty effect" may also appear in option valuations.

We also did not take up the issue of subjective estimates of probabilities. When pricing real options, managers may demonstrate the same over-optimism and illusion of control in pricing real options as they have in other risky choice contexts (March & Shapira, 1987) and as evident in the research on the winner's curse (Bazerman & Samuelson, 1983; Kagel & Levin, 1986).

A major challenge regarding the valuation of real options is whether managers are able to incorporate portfolio effects into the pricing of options. Because of possible correlations in the prices of their underlying assets, the value an option adds to a portfolio may differ from its value on a stand alone basis. Trigeorgis (1996: ch. 7) calls this the problem of "nonadditivity" of option values. By isolating each option pricing problem in the current study, we have left unexplored portfolio effects on perceived option values. In keeping our option problems as simple as possible, we have also not taken up the challenging problem of valuing compound options (i.e., options on options), which is a common type of investment problem managers face when making decisions about new ventures.

In the last decade, we have seen a growing volume of research applying option theory to problems of interest to managers.[18] Although finance research has helped managers frame decisions under uncertainty in option theoretic terms, their normative models for pricing options overlook key aspects of the behavioral and organizational contexts in which investment decisions occur. This initial study on behavioral option theory provides encouraging support for applying the insights from behavioral decision theory to understand how managers actually think about valuing real options.

ENDNOTES

[1] The one exception to this is real options on traded commodities.

[2] Behavioral decision theory also addresses biases in the assessment of probabilities. Studies on representativeness and availability address deviations in perceived distributions of possible outcomes from actual distributions (see, e.g., Kahneman, Slovic, & Tversky, 1982). Such biases may be quite relevant to managers' subjective valuations of real options. However, for this study, we provided respondents with objective distribution data.

[3] To further simplify the hypotheses we do not consider the role of decision weights for very small probabilities that can operate in contradiction to the value function (see Tversky & Kahneman, 1992).

[4] The unnecessary alternative assumption would be that option buyers and sellers increase already existing exposures.

[5] The alternative would be to assume that call sellers and put buyers take on uncovered positions.

[6] In the proofs, we also assume symmetry of preferences around the origin (i.e., $u(x) = -u(-x_i)$. We also make use of the facts that (1) risk aversion in the domain of gains implies $u(p_1x_1) > p_1u(x_1)$ and (2) risk seeking in the domain of losses implies $p_2u(x_2) > u(p_2x_2)$. These follow from the concavity of the prospect theory value function for gains and convexity for losses.

[7] The expected utility associated with buying the call option is $u(-y) + p_1u(x_1)$. The choice to buy the option turns on whether $p_1u(x_1) > -u(-y)$, that is, whether the expected

utility exceeds the disutility associated with the option purchase price. Risk aversion implies $u(p_1x_1) > p_1u(x_1)$. Assuming the utility function is symmetric and invertible, we have $p_1x_1 > y$.

[8] For the call option seller to enter into an option transaction, it must be that the expected utility associated with selling the option exceeds the expected utility associated with simply holding the asset. That is, $u(y) + p_2u(x_2) > p_1u(x_1) + p_2u(x_2)$, or $u(y) > p_1u(x_1)$. By risk aversion, $u(p_1x_1) > p_1u(x_1)$. Therefore, the seller is willing to offer a discount as long as $p_1x_1 > y > u^{-1}[p_1u(x_1)]$.

[9] Holding the lottery together with the put option creates a position equivalent to holding the call option.

[10] The put option buyer compares the expected utility with and without entering into the option transaction. To buy the put option, it must be that $u(-y) + p_1u(x_1) > p_1u(x_1) + p_2u(x_2)$, or $u(-y) > p_2u(x_2)$. By risk seeking, $p_2u(x_2) > u(p_2x_2)$. Hence, $-y > u^{-1}[p_2u(x_2)] > p_2x_2$. Thus, $-p_2x_2 > y$. The purchase price must be less than the absolute value of the expected loss.

[11] The put option seller must determine whether $u(y) + p_2u(x_2) > 0$. We can also write this condition as $y > u^{-1}[-p_2u(x_2)]$. Because of risk seeking for losses, we know $p_2u(x_2) > u(p_2x_2)$, or $u(-p_2x_2) > -p_2u(x_2)$. Thus, the put option seller is will sell the option for a price in the range $-p_2x_2 > y > u^{-1}[-p_2u(x_2)]$. This indicates a willingness to accept a discount relative to the absolute value of the expected loss.

[12] The simplest way to demonstrate this contention is to compare risk neutral and risk averse valuation of a call option. Consider a call option with probability p_1 of a payoff of

x_1 to which both a risk neutral and risk averse individual assign the same utility (i.e., the point of intersection of the two utility functions is at x_1). Now consider the implications of introducing a positive exercise price. Because of concave preferences, the risk averse certainty equivalent value, $u^{-1}[p_1u(x_1-e)]$, must exceed the risk neutral certainty equivalent value, $p_1x_1-p_1e$, reflecting linear preferences. Thus, for risk averse preferences, the reduction in call option value associated with introducing the exercise price is less than p_1e.

[13] Consider a put option on an asset with probability p_2 of a loss of x_2. Assume both a risk neutral and risk averse individual assign the same utility to x_2. Now consider the implications of introducing a positive exercise price. Because of convex preferences, the risk seeking certainty equivalent value, $u^{-1}[p_2u(x_2+e)]$, must be less than the risk neutral certainty equivalent value, $p_2x_2+p_2e$, reflecting linear preferences. Hence, the risk averse are willing to transact at a higher price (equal to the absolute value of the certainty equivalent) than the risk neutral. Thus, for risk averse preferences, the reduction in call option value associated with introducing the exercise price is less than p_2e.

[14] Setting the probabilities at .50, we avoid complications associated with extreme probabilities near zero and 1.00. These complications involve subjective interpretations that overweigh low probabilities and underweigh high probabilities, as discussed by Tversky and Fox (1995).

[15] For put options, the wording was changed from "lose" to "gain" for the item corresponding to x_2=-1000.

[16] The complete questionnaire is available from the authors.

[17] The 3-month treasury bill rate, a proxy for the risk-free rate, was about 4.5 percent at the time respondents filled out the questionnaire.

[18] Trigeorgis (1995; 1996), Amram and Kulatilaka (1999), and Brennan and Trigeorgis (2000) provide overviews of this research stream and its applications.

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TABLE 1
Option Pricing Questionnaire Items

Buying A Call Option

You are offered a call option on an investment that has a 50% chance to be worth $\$x_1$ and a 50% chance to be worth $\$x_2$.

For this option, I would be willing to pay: $_____

Selling A Call Option

You own an investment that has a 50% chance to be worth $\$x_1$ and a 50% chance to be worth $\$x_2$.

I would be willing to sell a call option on this investment to someone else for: $_____

Buying A Put Option

You own an investment that has a 50% chance to lose $\$x_1$ and a 50% chance to lose $\$x_2$.

For buying the option to transfer the outcome of this investment to someone else, I would be willing to pay: $_____

Selling A Put Option

You are selling to someone the option to transfer to you the outcome associated with an investment that has a 50% chance to lose $\$x_1$ and a 50% chance to lose $\$x_2$.

To sell this option, I would have to receive: $_____

Table 2
Descriptive Statistics and T Statistics for Simple Option Items

Item	N	Mean	Std Dev	Minimum	Maximum	Exp Value	T
01	63	577.06	147.90	200	750	750	-9.28
02	63	259.49	179.93	0	500	500	-10.61
03	63	28.11	71.07	0	350	500	-52.71
04	63	692.11	165.20	200	1001	750	-2.78
05	63	433.38	178.41	1	999	500	-2.96
06	63	168.84	220.13	0	1000	500	-11.94
07	63	488.87	232.51	0	800	750	-8.91
08	63	297.60	186.80	0	600	500	-8.60
09	63	104.48	149.48	0	500	500	-21.00
10	63	624.84	311.25	0	1001	750	-3.19
11	63	520.57	274.47	0	1001	500	0.59
12	63	288.49	274.90	0	1000	500	-6.11

Table 3
Descriptive Statistics for Implicit Discount Rates

Period	N	Mean	Std Dev	Minimum	Maximum
0-6 months	63	0.411	1.926	-0.778	14.530
6-12 months	63	0.179	0.293	-0.499	1.125
12-48 months	63	0.065	0.069	-0.084	0.260

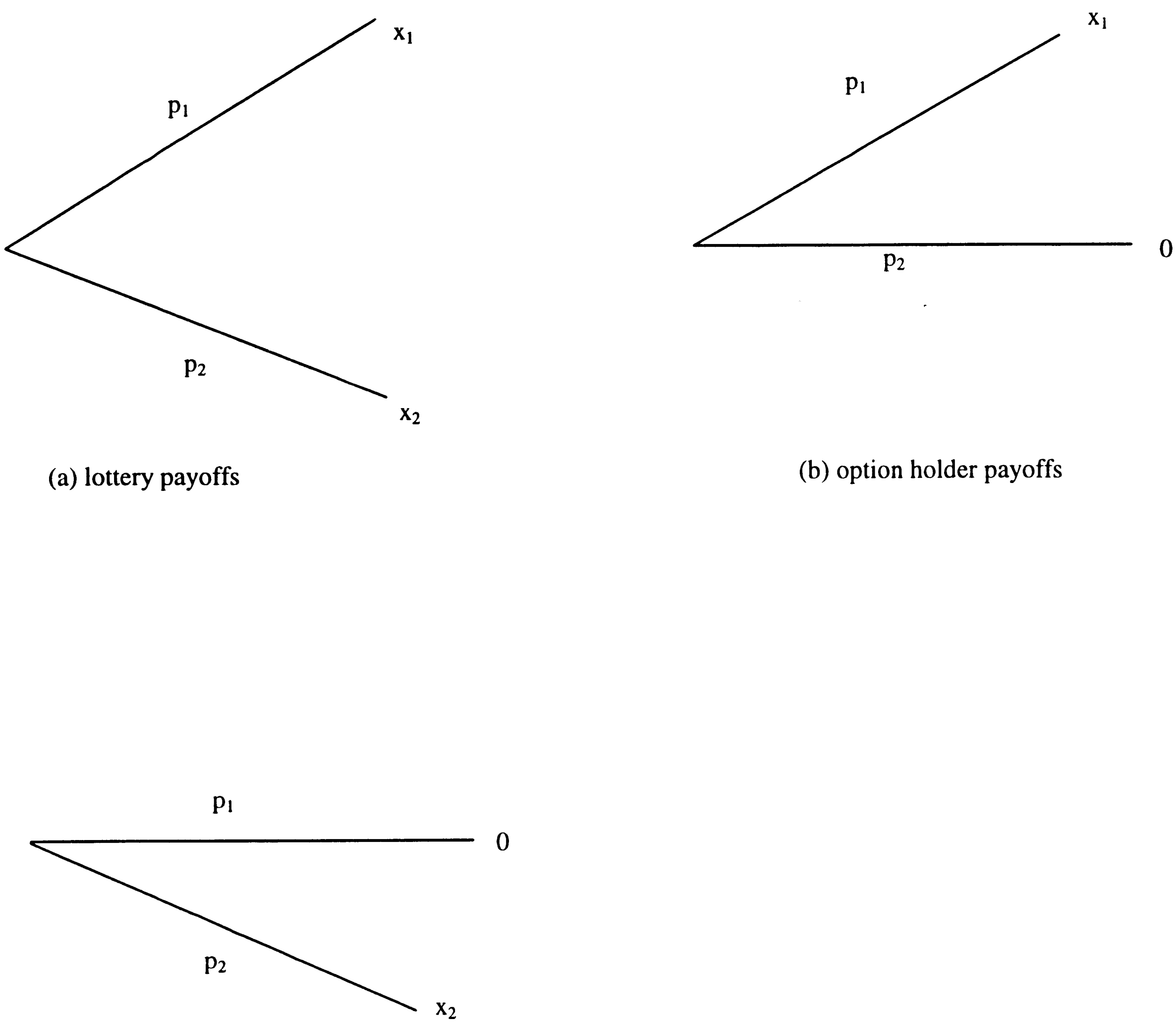
Table 4
Descriptive Statistics and T Statistics for Options with Exercise Prices

Item	N	Mean	Std Dev	Minimum	Maximum	Exp Value	T
01	62	218.00	274.86	0	750	125	2.66
02	62	167.26	170.81	0	500	250	-3.81
03	60	100.52	165.29	0	500	250	-7.01
04	61	283.13	284.92	0	800	125	4.33
05	61	258.46	204.38	0	750	250	0.32
06	61	170.70	179.49	0	600	250	-3.45
07	57	284.23	363.46	0	1500	125	3.31
08	57	199.60	238.13	0	1000	250	-1.60
09	57	146.07	199.96	0	750	250	-3.92
10	56	227.63	252.89	0	800	125	3.04
11	56	235.41	212.68	0	750	250	-0.51
12	56	236.48	217.95	0	750	250	-0.46

Table 5
Comparison of Options Without and With Exercise Prices

PART I				PART III				COMPARISON		
Item	N	Mean	Std Dev	Item	N	Mean	Std Dev	Mean	PE	T
01	63	577.1	147.9	01	62	218.0	274.9	361.5	375	-0.32
02	63	259.5	179.9	02	62	167.3	170.8	96.4	250	-4.78
03	63	28.1	71.1	03	60	100.5	165.3	-71.00	250	-14.36
04	63	692.1	165.2	04	61	283.1	284.9	406.3	375	0.66
05	63	433.4	178.4	05	61	258.5	204.4	175.2	250	-1.96
06	63	168.8	220.1	06	61	170.7	179.5	-1.2	250	-7.12
07	63	488.9	232.5	07	57	284.2	363.5	214.9	375	-2.96
08	63	297.6	186.8	08	57	199.6	238.1	107.4	250	-4.16
09	63	104.5	149.5	09	57	146.1	200.0	-40.2	250	-9.20
10	63	624.8	311.2	10	56	227.6	252.9	394.9	375	0.37
11	63	520.6	274.5	11	56	235.4	212.7	266.3	250	0.38
12	63	288.5	274.9	12	56	236.5	217.9	30.0	250	-5.48

FIGURE 1
Lottery and Option Payoffs



(a) lottery payoffs

(b) option holder payoffs

(c) option seller payoffs

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